



**EFFECT OF INCINERATOR FLY ASH IN CEMENT MORTAR TOWARD  
COMPRESSIVE STRENGTH AND LEACHING CHARACTERISTIC**

**NOORHIDAYU BINTI CHE HASMI**

**A thesis submitted in fulfillment of the requirements for the award of the degree of  
Bachelor of Civil Engineering**

**Faculty of Civil Engineering and Earth Resources  
University Malaysia Pahang**

**JUNE 2012**

PERPUSTAKAAN UNIVERSITI MALAYSIA PAHANG	
No. Perolehan <b>072601</b>	No. Panggilan 7A 440 - N66 2012 RS BC-
Tarikh <b>29 MAR 2013</b>	

## ABSTRACT

Today, incinerator used to burn municipal solid waste widely in developed countries including Malaysia. MWS fly ash produced from incinerator will donated a percentage of the material is disposed in landfill. Due to the increasing costs of landfill and the current interest in sustainable development, a lot of research has been done to recycle MWS fly ash utilization in Malaysia. This study was focus on the investigation of compressive strength, the presence of heavy metal leaching and microstructure of MWSI fly ash. The mortars cured for 7, 28, 60 and 90 days were tested for the compressive strength. The specimens (raw material, 10 and 30% FA) at 28 days were testing for presence of heavy metal leaching by using Inductivity Coupled Plasma (ICP) spectroscopy. Also, the specimens for mortar (30% FA) at age 28 days were tested by X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) test. From the result obtained the higher strength for compressive strength of MSWI fly ash mortar is 28.66 N/mm<sup>2</sup> for mortar which is 10% of total percentage MSWI fly ash that has been used in the specimens, but it still lower than control mortar (41.50 N/mm<sup>2</sup>). Leaching rates of heavy metals (Cr, Cu, Pb, Zn, Mn, Co, Ni, Sr, Cd, Sn, Ba) were recorded lower than the standard US Environmental Protection Agency (USEPA). XRD test has shown increment of calcium silicate hydrate (C-S-H) pattern for 28 and 90 days, while decreasing of pattern of calcite. This proves the presence of pozzolanic elements in mortar. SEM test also was strengthening the evidence that the form of change reaction of MSWI fly ash between 28 and 90 days. As a conclusion, MSWI fly ash safe to use as a replacement for cement in mortar by using solidification and stabilization process.

## ABSTRAK

Hari ini, insinerator telah digunakan secara meluas untuk membakar pembandaran sisa pepejal (MSW) di Negara-negara maju termasuklah Malaysia. Abu terbang MSW yang dihasilkan dari incinerator akan menyumbang kepada peratus bahan yang dilupuskan dalam tapak pelupusan. Disebabkan peningkatan kos untuk tapak pelupusan and faedah terkini dalam pembangunan yang lestari, banyak penyelidikan telah dilakukan untuk mengitar semula abu terbang MSW di Malaysia. Mortar yang dirawat selamat 7, 28, 60 dan 90 hari telah diuji untuk kekuatan mampatan. Specimen (bahan mentah, 10 dan 30% FA) pada 28 hari telah diuji kehadiran logam yang berat dengan menggunakan Inductivity Pasangan Plasma (ICP) spektrokopi. Juga, specimen mortar (30% FA) pada hari ke 28 telah diuji oleh Pembelauan X-Ray (XRD) dan ujian Imbasan Mikroskopi Electron (SEM). Pada akhir keputusan, kekuatan yang lebih tinggi untuk kekuatan mampatan abu terbang MSWI mortar adalah  $28.66 \text{ N/mm}^2$  bagi mortar 10% jumlah peratusan abu terbang MSWI yang telah digunakan dalam specimen, tetapi ia masih lebih rendah daripada mortar kawalan ( $41.50 \text{ N/mm}^2$ ). Kadar pengurusan logam berat (Cr, Cu, Pb, Zn, Mn, Co, Ni, Sr, Cd, Sn, Ba) telah dicatat lebih rendah daripada standard Agensi Perlindungan Alam Sekitar Amerika Syarikat (USEPA). Ujian XRD telah menunjukkan peningkatan corak kalsim silikat hidrat (C-S-H) dan penurunan corak calcite untuk 28 dan 90 hari. Ini membuktikan kehadiran elemen pozolanik dalam mortar. Ujian SEM juga telah mengukuhkan bukti bentuk perubahan reaksi MSWI dalam mortar antara 28 dan 90 hari. Sebagai kesimpulan, abu terbang MSWI selamat untuk digunakan sebagai gantian untuk simen dalam mortar dengan menggunakan proses pemejalan dan penstabilan.

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Overview of Research**

Cement concrete is the most widely used as construction material all over the world. The reasons for such widespread use of cement concrete is due to its easy adaptability, durability, strength, availability, easy for construction and overall economy in construction. The strength development of concrete is depending on the curing age, the use of admixture and other factors.

An admixture is define as the material added in small quantities to cement concrete, mortar or grout during mixing or before mixing to modify the properties both in fresh and hardened states. Several materials have been used for addition in cement concrete or mortar to improve certain properties as required for a specific purpose and situation. Use of admixture in cement concrete, mortar or grout makes it possible to improve the properties of concrete both in fresh and hardened states. This facilitates in achievement of desired quality at site.

Nowadays, blending cement with fly ash (FA), silica fume or a natural pozzolan using FA in concrete is widespread in practice. The uses of FA in concrete has been improved the properties of concrete in both fresh and hardened states, with

improvement to workability, strength, drying shrinkage, temperature rise and abrasion resistance.

Municipal solid waste (MSW) is the wastes collected from many places and areas such as residential, commercial, institutional and some industrial areas. It has been collected and managed by municipalities and growing faster than population due to increase of consumption rate. MSW is the main concern and has major impacts to environmental and human health.

Incineration has been widely used technology for disposal of MSW at developed country. This technology produces solid residue composed of bottom, fly ash and scrubber residue. Three percent from the mass of the unburned MSW is fly ash. Fly ash is regarded as hazardous waste due to its high concentration of leachable heavy metals and in some cases, to the existence of toxic chlorinated compounds (J.R Conner, 1990).

By using Municipal Solid Waste Incinerator (MSWI) fly ash as replacement for cement is able to save the environment. It solved the storage and disposal problem of FA. The fly ash will be a potential resource as a new product, such as cementitious product (Al-Almoudi and Maslehuddin, 1996; McCarthy and Dhir, 1999), be a grout mixes (Akram et al., 1994) and stabilizing clay based building materials (Termimi et al., 1995).

## 1.2 Problem Statement

Fly ash is an industrial by-product which also recognized as an environmental pollutant. The exploitation of fly ash in construction must be taken into consideration in term of result and potential from previous research. Many possible advantageous applications of fly ash are being evaluated to minimize waste, decrease cost of disposal and provide value-added products.

Generally, municipal incinerator fly ash (MSWI) was disposed in landfill after a preliminary treatment such as advanced separation process, chemical stabilization or encapsulation, solidification/stabilization with inorganic binders such as cement, powdered blast furnace slag or calcium sulphate. These pre-treatment is needed in order to reduce the hazardous characteristics of MSWI fly ash.

Although Malaysia still do not widely practice the disposal of municipal solid waste by incineration, but it is not impossible that one day Malaysia will adopt this method because the current situation shows that the percentage of municipal solid waste generation increased from year to year. The best way to reduce the fly ashes disposes to the landfills, it is by treat them and used as a cement replacement.

### **1.3 Objective of study**

1. To determine the effectiveness the potential of MWSI fly ash as a replacement of cement base on compressive strength
2. To identify the presence of leaching characteristic from MSWI fly ash in mortar
3. To determine the microstructure of MWSI fly ash in mortar



#### 1.4 Scope of study

This study concentrated on the influence of special admixtures on quality of concrete especially a MSWI fly ash. This study is focus on investigation of compressive strength, the presence of heavy metal leaching and microstructure of MWSI fly ash. The sample of fly ash was taken from Recycle Energy Sdn Bhd (RESB) Semenyih.

The mortar produced from the material are a commercially available Portland cement equivalent to ASTM Type I cement, where suitable for floors, reinforcement concrete structures, pavement and etc. The mortar were prepared based on proportion of 1 : 0.275 : 0.85 (cementitious materials : sand : water) by mass. Fly ash was used as replacement of cement, at the level of 0, 10, 20 and 30 % by the total weight of ordinary Portland cement. Meanwhile, control mortar were prepared without replacing ad FA ( FA – 0%).

Mortar cube dimension of 50 x 50 x 50 mm were tested for compressive strength, heavy metal leaching and microstructure of MSWI fly ash mortar. All specimens' mortar were cast and poured into mould and the hardened mortar was taken out from the mould after 24 hours.

The mortars cured for 7, 28, 60 and 90 days were tested for the compressive strength. The specimens (raw material, 10, 30 % MSWI fly ash) at 28 days were testing for presence of heavy metal leaching by using Inductivity Coupled Plasma (ICP) spectroscopy. Also, the specimens for mortar (30%FA) at age 28 days were tested by X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) test.

At the end of the research, the result was expected that by using MSWI fly ash as cement replacement will give a good result towards compressive strength of mortar. From MSWI mortar, the presence of leaching characteristic will be detected and the microstructure of MSWI fly ash will be identified. So, the research are expected to find MSWI fly ash have a potential as a replacement of cement.

## 1.5 Significant of study

In the past, coal combustion produced by fly ash was simply entrained in flue gases and dispersed into the atmosphere. The created environmental and health concerns that prompted laws which have reduced fly ash emissions to less than 1 % of fly ash produced. Worldwide, coal power stations were produce more than 65% of fly ash, where it is disposed in landfills and ash ponds. Today, incinerator was used to burn municipal solid waste widely in developed countries including Malaysia. MWS fly ash produced from incinerator will donated a percentage of the material is disposed in landfill.

According to U.S coal-fired power plants, 2005 reported that 71.1 million tons of fly ash was produced, and 29.1 million tons were reused in various applications. Masoud Aghajani Mir et. Al, 2009 reported that the potential of MSW and Refuse Derived Fuels (RDF) generation by 2020 in Kuala Lumpur claimed that they need around 11 plants to treatment of MSW that this number of plant are able to produce around 62.7 MWh electricity per days. Nowadays, because of increased costs of landfill and the current interest in sustainable development, a lot of research was done to recycle MWS fly ash utilization in Malaysia.

So, due to environmental factors, many studies had conducted on MSW fly ash recycling to be used as a replacement for Portland cement. But, this study focuses on the compressive strength, the presence of the leaching characteristics and microstructure of MSWI mortar.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction And Historical Background

Admixtures are ingredients other than Portland cement, water aggregates that may be added to concrete to impact a specific quality to either the fresh (plastic) mix or the hardened concrete (ASTM C494). Based on research Kasmata and Panarese, 1988 were identify four major reasons for using admixtures. There are to reduce cost of concrete construction, to achieve certain properties in concrete more effectively than by other means, to ensure quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather condition and to overcome certain emergencies during concrete operations.

Referring to in the concrete and aggregate section of the ASTM standards, fly ash is a finely divided residue the results from the combustion of ground or powdered coal and that is transported by flue gasses (ASTM C618). Also, the fly ash is defined;

- (i) the burning of municipal garbage or any other refuse with coal.
- (ii) the injection of lime directly into the boiler for sulphur removal
- (iii) the burning of industrial or municipal garbage in incinerator commonly known as 'incinerator ash' do not lead to fly ash could be used in cement, mortar, or concrete production.

The use of fly ash as a pozzolanic ingredient was discovered as early as 1914, while the earliest noteworthy study its use was in 1937 (Halstead, W.1986). At United States, fly ash used in concrete in the early 1930's. R.E. Davis from University of California studied the first comprehensive study in 1937. From Kobubu, 1968 reported that the major breakthrough in using fly ash in concrete was the construction of Hungry Horse Dam in 1948. This utilizes about 120,000 metric tons of fly ash. Because of that U.S Bureau of Reclamation decided to paved the way for using fly ash in concrete construction.

## **2.2 The Municipal Solid Waste Fly Ash**

Solid waste is any scrap material or other surplus substance or rejected products arising from the application of any process. It also know as any substance required to be disposal of as being broken, worn out, contaminated or otherwise spoiled or any other material that is required by the authority to be disposal. (Solid Waste and Public Cleansing Management Act 2007)

In United Kingdom, solid waste is defined as any material or an effluent and other undesired surplus that comes up from the application of any process that needs to be disposed or have been broken, contaminated or damaged. It also related with anything which needs to be cast off or else it were waste and shall be anticipated as waste except conflicting is verified (The UK's Environmental Protection Act 1990)

Solid waste management and integrated waste management is the method used for controlling, collection, disposal and treatment of all the solid wastes or municipal solid waste generates in the communities. It can be any of solid waste treatment processes such as landfill, composting, recycling and incinerator treatment. The main purpose of solid waste management is to reduce and minimize the amount of waste disposal in the environment.

Municipal solid waste ash (MSWA) is the by-product produced from the combustion of municipal solid waste (MSW). Rafat Siddique, 2010 reported that Incineration municipal solid wastes have two processes, that are the refuse-derived fuel (DRF) process and the mass-burning process. The refused-derived fuel process consists of first separating metals and glass from the MSW. The MSW is shredded and incinerated, and the generated heat is recovered to produce electricity. The mass-burning process consists of burning of the MSW as it is received in the plant without waste separation or shredding.

Chimenos and Kamon et al.,2000 said that, in 2000 the estimated amount of fly ash generated by burning municipal solid waste in USA, Japan and the European Union was about 25 Mt/year. This make the amount of ashes derived from the combustion of fuels to be dealt with is increasing. Increased combustion and growing restriction regarding the emission of particles to the atmosphere are contributing to this trend. (Lopez et al.,2003)

Most municipal solid waste (MSW) is incinerated in Taiwan. That produces about 250,000 tons of fly ash and scrubber-ash annually. The resulting ash waste contains hazardous heavy metals. (Huang CM, in Waste Manage 2006). Solidification / stabilization (S/S) is a method for safe disposal in landfill sites. However, leaching of heavy metals is still possible in the long term.

According to economic and ecological benefits, the fly ash in concrete able to improves its workability, reduces segregation, bleeding, heat evolution and permeability, inhibits alkali-aggregate reaction, and enhances sulfate resistance. Based on Helmult 1987 said the use of fly ash has increased on the last 20 years, less than 20% of the fly ash collected was used in the cement and concrete industries.

Municipal Solid Waste Incineration (MSWI) fly ash contained easily leachable heavy metals and potentially toxic dioxin. That is regarded as hazardous and must be disposed by landfilled after solidification/stabilization (J.E. Aubert, 2004). In Shanghai, 20,000 tonnes of MSWI fly ash per year is produced and it has to be placed into a safe landfill.

But, this landfill amounts will rapidly increasing in several years due to municipal solid waste incineration. By mixing together MSWI fly and Portland cement or other binder materials will produce solidification/stabilization process. This is will reduce the net volume for hazardous waste filled in the landfill.

### **2.3 Physical Properties of Municipal Solid Waste Fly Ash**

Based on ASTM C618, have two major classes of fly ash. It is divide on the basic of their chemical composition resulting from the type if the coal burned. These are designated Class F and Class C. Class F is fly ash with pozzolan properties and Class C is fly ash with pozzolan and cementitious properties. Class F fly ash usually has less than 5 % lime, CaO but mat contain up to 10 %. Class C fly ash has 15% to 30 % CaO.

Halstead, 1986 found that in some of the western states of the united Class F is fly ash normally produced from burning anthracite or bituminous coal. Class C is generally produced from burning of subbituminous coal and lignite. Also, from Halsted report, class C fly ash usually has cementitious properties in addition to pozzolanic properties due to free lime, and Class F is rarely cementitious when mixed with mater alone.

The fly ash cools into spheres, which may be in the form of solid, hollow (cenospheres), or hollow and filled with other spheres. Particle diameter range is from 1  $\mu\text{m}$  to more than 0.1  $\mu\text{m}$ , with an average of 0.015  $\mu\text{m}$  to 0.020  $\mu\text{m}$ , and is 70% to 90% smaller than 0.045 mm. The spherical shape of fly ash increases the workability of the fresh concrete.

In addition, both fly ash and silica fume extend the hydration process, allowing a greater strength development and reduced porosity. From research shown concrete contain more than 20 % pozzolan by weight of cement has a much smaller

pore size distribution than Portland cement without fly ash [Michael S.Mamlouk and John P.Zaniewski, 1999]

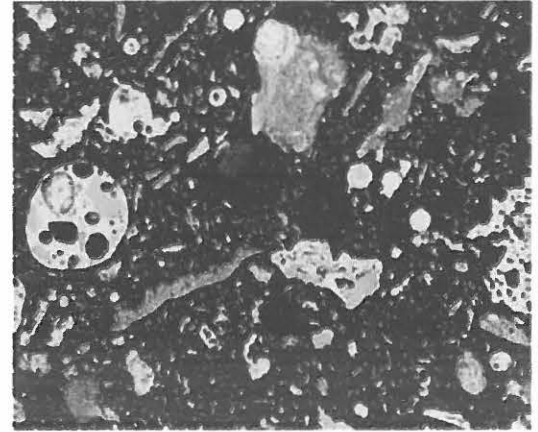
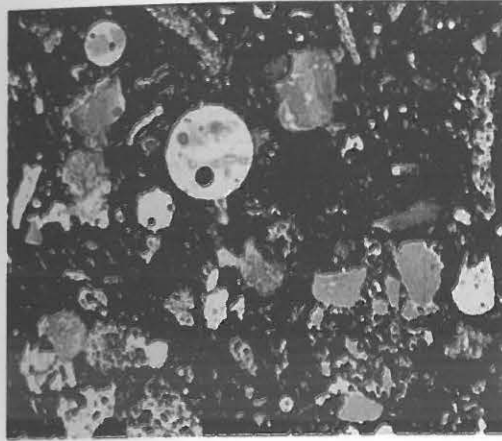
Incinerator ash results from burning municipal solid waste and has two components, bottom ash and fly ash. From total burnt ash, a incinerator produce 80% bottom ash and 20% fly ash (Rivard-Lentz DJ, 1997). USEPA 1990 reported that, bottom ash generally consists of coarse particle (0.1 – 100 mm) of slag, glass, rocks, metals and unburnt organic matter. Also, fly ash consists of small diameter particles (1- 500 $\mu$ m) of burnt or partially burnt organic matters, on which various components of the flue gas have condensed.

Municipal solid waste fly ash is in the form of a grey to black amorphous, glasslike material. It contains high levels of several toxic matels such as lead and cadmium and organic compounds such as dioxins. The quality of MSW ash depends greatly on the nature of the waste, type of combustion unit, and nature of the air pollution control device. From research Eighmy and Gress, 1996 that the bulk specific gravity ranges from 1.5- 2.2 for sand-size or fine particles. Koppelman and Tanenbaum, 1993 reported that 1.93-2.44 for coarse particles, compared with approximately 2.6-2.8 for conventional aggregate materials.

Another research form Chesner et al., 1986 said that municipal solid waste combustor ash is a relatively lightweight material compared with natural sands and aggregate. Combustor ash is highly absorptive with absorption values ranging from 12 to 17% for fine particles and from about 4.1 to 4.7% for coarse particles.

Research by Remold et al. 2002 stated that the backscattered electron images of the MSWI fly ash for the two fields of observation, Figure 2.0 (a) and (b). That can be seen that MSWI fly ash has various forms, unlike coal fly ash that is composed of spherical particles. Some MSWI fly ash particles are spherical whether full or hollow, and a relatively large fraction of the ash appears to have a vitreous form. Also, there are elongated, angular, very porous particles and clusters of sintered particles.





(a) MSWI fly ash (FA1) (500 X 400 $\mu$ m)

(b) MSWI fly ash (FA2) (500 X 400 $\mu$ m)

**Figure 2.1** (a) and (b). The backscattered electron images of the MSWI fly as

#### 2.4 Chemical Properties of MWSI Fly Ash

Fly ash addition in concrete will choose depend on classification of type fly ash Class C or Class F. It should meet the ATM C618 requirements. Unclassified fly ash cannot be used to replace cement due to its low chemical reactivity. The characterization of MSWI fly ash where carried out from Waste incineration plant in Lagny, France, by Remond et al.2000 have main oxide components of fly ash such as  $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{Al}_2\text{O}_3$ . Also, the ash has high chlorine, sodium and potassium contents. The loss on ignition at 975°C was also very high (13%). The most abundant heavy metals were zinc and lead.



**Table 2.1:** Chemical composition of MSWI fly ash (Remond et al., 2002)

Compounds		Heavy metals	
compound	Mass fraction (%)	Metal	Content (mg/kg)
LOI (975)	13.00	Zn	11000
SiO	27.23	Pb	4000
CaO	16.42	Cu	670
AlO	11.72	Mn	600
NaO	5.86	Cr	450
KO	5.80	Cd	270
MgO	2.52	Sn	180
FeO	1.80	Sb	110
TiO	0.84	Ni	50
PO	0.34	Se	50
MnO	0.05	Te	46
SrO	0.01	V	32
Ba	0.22	Mo	25
Cl	7.20	As	21
SO	3.00	Co	21
		Tl	<5

MSWI fly ash is mainly composed of silica, calcium, alumina oxide and iron oxide, which are quite similar to those of complementary cementitious materials presently commonly used such as granulated blast-furnace slag (GGBFS) and coal fly ash (FA). So, MSWI fly ash could be having pozzolanic or hydraulic behavior and its addition to the cement could have a beneficial role in the development of the hydrated cement paste.

## 2.5 Effect of Using MSWI Fly Ash As A Replacement Cement In Mortar

It is generally agreed that the use of fine fly ash will improve the properties of concrete. The cement concrete elements also undergo change in dimensions under various conditions of loading, temperature changes and cement hydration. Various condition members occur due to elasticity, shrinkage, creep and thermal changes.

Various methods of treating MSWI fly ash such as melting, solidification/stabilization (S/S), acid extraction, vitrification and sintering have been used to treat MSWI fly ash. (Hui-Sheng Shi et.al., 2008). Among them, the most frequently applied approach to minimize the environmental impact of MSWI fly ash is the S/S technology, which gives the possibility of reusing the final materials. A major factor is that cement is easy to form a durable, monolithic material that will not easily leach hazardous components under the disposal condition. (P.G Baker et.al., 1997).

The report from Li-li Kan et.al., 2008, shows that the MSWI fly ash has some cementitious activity, but the reactivity is relatively lower and its addition to cement may lead to retardation of cement hydration. After incorporation of common mineral admixtures, the strength of solidified body was enhanced, and the effect of the heavy metals-immobilizing may be reinforced.

For reuse as a resource, MSWI fly ash has been used directly or used after scouring to remove chlorine, for partial replacement of cement for concrete. But, fly ash concrete cannot prevent the leaching of heavy metal still exist. (Aubert JE, 2007). Studies from Nishigaki M, 2000 have shown that the use of the molten slag of fly ash to form permeable blocks and pavement bricks may greatly reduce the possibility of heavy metal leaching.

Strength of fly ash concrete is influenced by type of cement, quality of fly ash and curing temperature compared to that of non-fly-ash concrete proportioned for equivalent 28 day compressive strength. Concrete containing typical Class F fly ash may improve lower strength at 3 or 7 days of age when tested at room temperature.

However, fly ash concrete usually have higher ultimate strengths when properly cured. The gain of strength is the result of the relatively slow pozzolanic reaction of fly ash. On cold weather, the strength gain in fly ash concrete can be more adversely affected than the strength than the strength gain in non-fly-ash. Therefore, precautions must be taken when fly ash is used in cold weather.

## 2.6 Compressive Strength

The compressive strength of concrete is the most common performance measured. Concrete and mortar mixtures can be designed to provide a wide range of mechanical and durability properties to meet the design requirements of a structure. The compressive strength is calculated from the failure load divided by the cross-sectional area resisting the load and reported in unit of pound-force per square inch (psi) in US Customary units or mega-pascals (MPa) in SI unit.

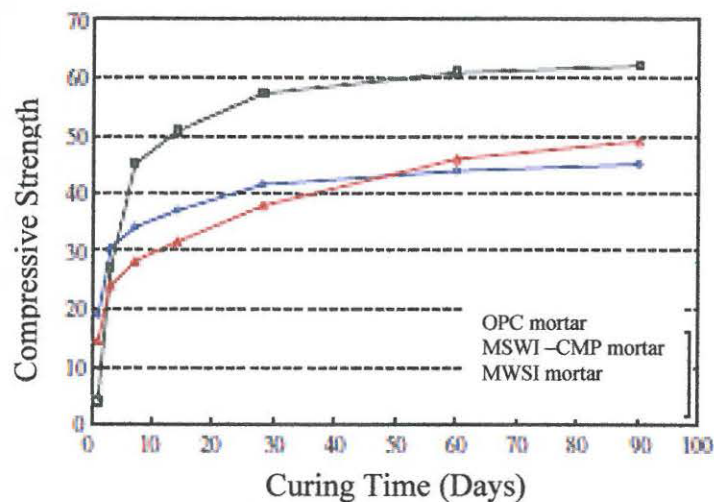
Research by Taha et al showed that in concrete, partial replacement of cement by incinerator fly ash results in lower compressive strength at early ages range 3 to 6 months. The greater strength of concrete is beyond 6 months. The higher strength is the result of increased pozzolanic reaction with time. That is producing an growing amount of calcium-silicate-hydrate (C-S-H) at the expense of calcium hydroxide (C-H). This phenomenon is usually happen when a function of amount, reactivity and fineness of the ash. A longer curing periods and lower water to cement ratios produce concrete with higher compressive strengths. (Taha et al.,2000).

Amer Ali Al-Ramas et al. 2004 reported the the potential use of incinerator ash as a replacement for cement and sand in cement mortars, shown that the maximum compressive strength of  $36.4\text{N/mm}^2$  was achieved using 20% incinerator ash after 28 days of curing. The maximum compressive strength of  $27.4\text{N/mm}^2$  was achieved using 20% incinerator ash after 28 days of curing.

Also, Al-Amoudi et al found that 20% fly ash replacement for cement in mortar performs better than plain mortars with respect to compressive strength, pulse velocity, porosity, permeability and time –to-initiation of reinforcement corrosion. Comparable result was found by Taha et.al. The mortars containing up to 20%fly ash produced higher compressive strengths than the control mixture (0% fly ash)

Besides, report from Amer Ali Al-Ramas et. Al., 2003 about use of incinerator ash as replacement from cement and sand in cement mortars were conclude that the mortar prepared using 20% incinerator ash replacement for cement yielded equal or a higher compressive strength than the control mix after 14 and 28 days of curing. The maximum compressive strength of 27.4 N/mm<sup>2</sup> able to achieved using 20% incinerator ash after 28 days.

As a structural material, the compressive strength of MWSI slag-cement in mortar develops more slowly than that of plain cement mortar in the early stage. But can catch up after that. Lee TC et.al, 2008 about the slag-cement mortar made with cement and slag vitrified from MWSI fly ash has been shown in studies of mortar with 20% cement replacement with a vitrified mix of fly ash, bottom ash and glass frit.



**Figure 2.2 :** Evolution of compressive strength for OPC Mortar, MSWI mortar and MSWI-CMP mortar at Taiwan